FUNCTIONAL RANGE OF MOTION DURING GRASP: IMPACT OF THE OBJECT LOCATION

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Abstract- **In this study we determined the Functional Range of Motion (F_ROM) of arm and hand joints for various functional tasks and different locations of the objects to be grasped. The data for F_ROM were collected in six healthy volunteers who used seven selected objects typical for daily activities. Subjects grasped the objects from six different locations marked at the working desk. The recorded data comprised nine hand and arm joint angles measured by Penny & Gilles flexible goniometers and torziometers during the reach/ grasp/ release tasks. The F_ROM was defined as a difference between the maximum and the minimum joint angle; it was calculated for each task and for each object location. The Active Range of Motion (A_ROM) was also measured for each of nine joints' motion. Here we present only characteristic results for the elbow flexion, the thumb adduction, and the index finger proximal-inter-phalangeal (PIP) flexion, and two object locations. In order to characterize numerically the recordings we defined the location impact (LI) and task impact (TI). There is a statistically significant difference in both indices; thus, it was possible to use the indices as the measure of the difficulty for accomplishing a task based on the location. This measure is of special importance for selecting the exercise during rehabilitation of humans with disability, as well as for assessing the improvement in function during rehabilitation.**
***Keywords* - functional range of motion, reaching, grasping, neurorehabilitation, tasks**

I. INTRODUCTION

The maximum range of a joint rotation generated by voluntary activity is usually called *Active Range of Motion* (A_ROM) [5]; it refers to the amount of motion available to a joint within the anatomic limits of the joint structure (e.g., elbow flexion/extension was found to range from 140 to 146 degrees [3]). The A_ROM is determined by a number of factors, including the shape of the joint surfaces, the joint capsule, ligaments, and surrounding musculotendinous structures. In some joints there are no bony limitations to motion and the range of motion is limited by softy tissue structures. Other joints have bony limitations (e.g. humeroulnar joint is limited in extension by bony contact of the ulna on the olecrouon fossa). Gender is an influencing factor in some joints' motions [e.g., 1,2]. Physical conditions, as well as the age affect the A_ROM.

Functional Range of Motion (F_ROM) has been frequently used as an indicator of joints' mobility during functional movement [e.g. 4]. The F_ROM is task dependent, and it is smaller than A_ROM. Functional tasks are as a rule accomplished by multi-segmental (multi-joint) movement that requires specified range of joints' motion.

We hypothesized that the task and location have statistically significant impact on the joints' F_ROM, and that the impact can be used as a measure of the difficulty important for selection of the appropriate rehabilitation treatment as well as the measure of the progress in the rehabilitation [e.g., 6]. More precisely, the application of location and task impacts is important in rehabilitation that involves exercise of functional activities. By conditioning the task and the location of object one can adjust the course of therapy to the individual based on his/her abilities. The results of the study are the tables of impacts for nine joint angles crossed with six locations and seven tasks. Here we describe and discuss only the results for three joint rotations (elbow flexion, thumb adduction and index finger PIP flexion), and two locations contralateral-distal and lateral-proximal).

II.METHODS

A total of six healthy subjects (2 female and 4 male; mean ± std: age=34,8±6,9 years; mass=73,3±19,8 [kg] and height=173,0±7,8 [cm]) volunteered in the study. None of the subjects had a history of a neurologic or muscular abnormality. The subjects were instructed to perform seven simple tasks (e.g., drinking from a can, writing with a pen, using the VCR cassette). Subjects were seated relaxed facing the working desk, Fig.1. The joints of the preferred arm and hand were instrumented with flexible goniometers (Penny and Giles, Blackwood, U.K.), and the hand was resting at the desk in a half-supine position. All movements started from the same initial position: upper arm comfortably adducted, forearm flexed about 60^o, and hand closed loosely with thumb and index finger touching each other. The fingertip starting post was always in the center of subject's most convenient place within the working space (resting position). All movements ended at the position very close to the initial (resting) position. Subjects were asked to maintain the trunk

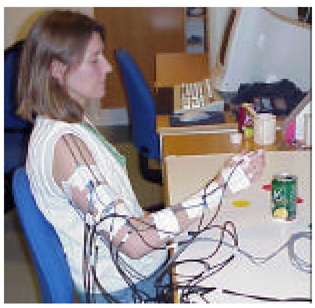

Fig.1 Movements are assessed by 3 two and 2 single axis goniometers and 2 torsiometers (Penny & Giles, UK) measuring 9 joint motions during task performance. Subjects were instructed to wait for audio signal from evaluator and subsequently pick up the object as accurately as possible with self-paced speed and complete task within 10 s. Grasping objects were: full can, almost empty can, mug, comb, pencil, VCR-cassette, CD diskette.

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stable, and to minimize the movement of the shoulder joint (protraction/ retraction, depression/ elevation). VCR recordings have been used for inspection of the sessions. Three directions and two distances were selected within the working space determining six different locations called object posts (Table I).

TABLE I
OBJECT LOCATIONS*

Location $\#N^0$	contra lateral	medial	lateral
distal	1	3	5
proximal	2	4	6

*Tasks #1 to #5 were performed from all 6 objects' locations;
Tasks #6 and #7 were performed from locations #1, #2, #5 and #6.

Seven tasks (Table II) have been selected from typical activities of daily living (ADL).

TABLE II
EXPERIMENTAL TASKS

Task # N^0	Action
1	Drinking From a Full Can
2	Drinking From an Almost Empty Can
3	Drinking From the Mug
4	Using Pencil
5	Using Comb
6	Manipulating VCR
7	Manipulating CD

The tasks were selected to embrace different grasping mode (palmar, lateral and precision grasp), as well as different loading conditions. Nine joint angles (Table III) have been measured using goniometers attached to the trunk, shoulder, upper arm, forearm and hand as shown in Fig. 1.

TABLE III
RECORDED JOINT MOTIONS

Joints' Rotation # N^0	Action
(1)	Elbow Flexion/Extension
(2)	Humeral Rotation
(3)	Supination/Pronation
(4)	Thumb Adduction
(5)	Index Finger PIP Flexion
(6)	Wrist Radio/Ulnar Rotation
(7)	Wrist Palmar/Dorsal Rotation
(8)	Shoulder Abduction/Adduction
(9)	Shoulder Flexion/Extension

Recordings were pre-processed by a custom made 12-channel interface amplifier. The pre-processing included a 50 Hz notch-filter and fourth ordered active low-pass filtering at 100 Hz. The gain and the offset were set at each of the channels: 0 V at 0 degrees, and 2.5 V at 90 degrees. An SCB-68 connector block, a PCI-16E-1 A/D NI board, and a custom-made software running within the LabView 5.1 environment have been used for data acquisition. Recordings were visually inspected and those that differed significantly from the required task were excluded from later analysis. Three trials were normalized, averaged and smoothed**.** The onset and the end of the movement were computed automatically from the velocity signal with the use of the following threshold: wrist velocity @ 5 percent of the maximum velocity. F_ROM was calculated as the difference between maximum (MAX) and minimum (MIN) angular value for each joint motion and object location (loc#i).

Statistical analysis was performed on F_ROM of the three joints between the two locations and among seven tasks using one-way ANOVA. In order to get a numerical scoring of the impact of location and task on changes of both MINIMUM (or MAXIMUM) angular values and F_ROM, we defined location impact and task impact.

The location impact ($LI^{i,j}$) between the two locations *#i* and *#j* was defined with Equations 1 and 2:

$$LI^{i,j}{}_{MIN} = \left| \frac{MIN(loc\#i) - MIN(loc\#\,j)}{F\_RPOM\,(loc\#i) - F\_ROM\,(loc\#\,j)} \right| \quad (1)$$

$$LI^{i,j}{}_{MAX} = \left| \frac{MAX\,(loc\#i) - MAX\,(loc\#\,j)}{F\_RPOM\,(loc\#\,i) - F\_ROM\,(loc\#\,j)} \right| \quad (2)$$

where *MIN(loc#i)* is for minimum angle from the location *# i*, (*i,j=1 to 6*).

The task impact (TI_{MIN}) of minimum (*MIN*) angles was defined for each object location with the Equations 3 and 4:

$$TI^{\min}{}_{MIN} = \min\{\frac{MIN(Task\#i) - MIN(Task\#\,j)}{F\_RPOM\,(Task\#i) - F\_ROM\,(Task\#\,j)}\} \quad (3)$$

$$TI^{\max}{}_{MIN} = \max\{\frac{MIN(Task\#i) - MIN(Task\#\,j)}{F\_RPOM\,(Task\#i) - F\_ROM\,(Task\#\,j)}\} \quad (4)$$

where min (max) are for minimal (maximal) values of the calculated *TI*, (*i,j*=1 to 7).

The task impact (TI_{MAX}) of maximum angular values was defined accordingly (TI_{MAX}^{min} and TI_{MAX}^{max}).

III. RESULTS

Functional range of movement was obtained for each arm/hand joint motion (Table III) during different tasks (Table II) and for each location (Table I). In total 342 F_ROM (9 joint motions x (5 tasks x 6 locations + 2 tasks x 4 locations)) were determined and averaged across 6 subjects (mean ± std). A_ROM was calculated for all nine joint rotations, and averaged for six subjects (mean ± std). A typical representative set of F_ROMs and the corresponding A_ROM are shown in Fig. 2 for three joints when subjects performed all seven tasks from two different locations. Elbow flexion (top), thumb adduction (middle) and index finger PIP flexion (bottom) functional ranges of motion are, as it would be expected, within physiological limits (A_ROM) shown with gray rectangles. F_ROM for elbow flexion, thumb adduction and index finger PIP rotation was statistically different between 7 performed tasks calculated for location #1 (one-way ANOVA, $p<0.01$). The same was found for the location #6. Statistically different functional ROM was found between two object locations, #1 and #6 (mean ± std =57.2 ± 22.7 *vs* 43.1 ± 22.8, $p<0.01$ for elbow flexion; 20.4 ± 4.2 *vs* 17.8 ± 3.2, $p<0.01$ for thumb adduction; and 24.3 ± 8.9 *vs* 22.5 ± 7.8, $p<0.01$ for index finger PIP flexion). They

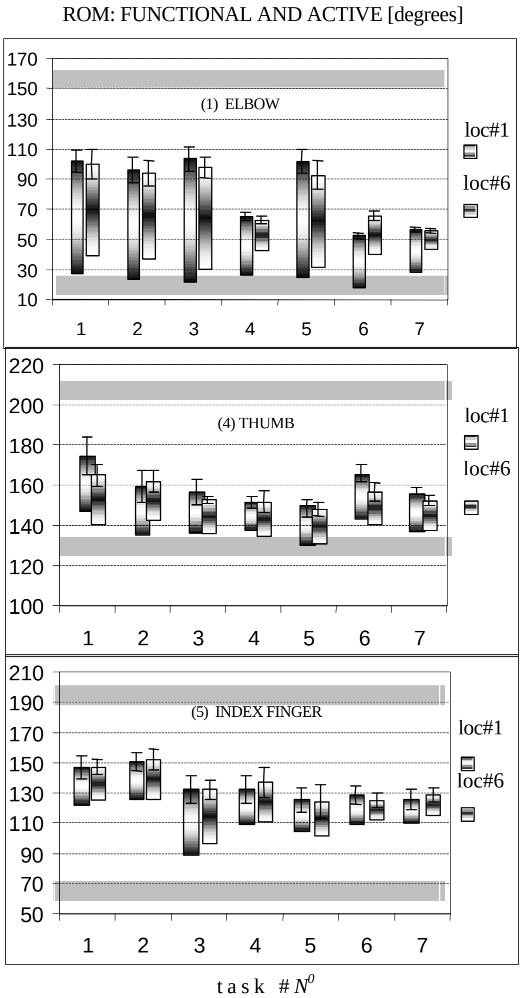

Fig.2 F_ROM (mean ± std, n=6 subjects) for: elbow flexion (top panel); thumb adduction (middle panel) and index finger PIP flexion (bottom panel) from locations #1 and #6 (see legend) in 7 tasks, Tabs I, II and III. A_ROM is presented with joints' minimum and maximum values shown by grey rectangles ([mean – std, mean + std], n=6 subjects).

represent 43, 25, and 19 percent of the A_ROM of the elbow, thumb and index finger joints, respectively when the object was at the location #1, compared to 33, 21, and 16 percent when object was at the location #6.

Figure 3 is a detailed presentation of minimum (left column-MINIMUM) and maximum (right column-MAXIMUM) angular values of joints' motions from Fig. 2. One-way ANOVA shows significant difference between the two locations for minimum (upper left column) and among tasks for maximum (upper right column) elbow flexion. On the contrary, the difference among the tasks for minimum and between the two locations for maximum elbow flexion are not significant. The difference between the two locations and among seven tasks for thumb adduction maximum and minimum values (middle left and right columns) and index fingers PIP flexion (bottom left and right columns) is not significant. Location impact between the two locations #1 and #6, calculated using equations 1 and 2 from Methods summarizing data from Figs 2 and 3 is in Table IV.

For example, location impact of minimum elbow flexion for task #6 when VCR-cassette post was moved from loc #1 to loc #6 was calculated using the following data: from Fig.2-upper panel (task #6):

F_ROM(loc#1)=33,57 and F_ROM(loc#6)=25,06;

and from Fig.3-upper panel, left column (task #6)

MIN(loc#1)=19,18 and MIN(loc#6)=40,41;

$LI^{1,6}_{MIN}=ABS[(19,18-40,41)/(33,57-25,06)]=2,49.$

Location impact of maximum elbow flexion for task #6 was calculated using the same data for F_ROM(loc#1) and (loc#6); and from Fig.3-upper panel, right column (task #6):

MAX(loc#1)= 52,76 and MAX(loc#6)= 65,47;

$LI^{1,6}_{MAX}=ABS[(52,76-65,47)/(33,57-25,06)]=1,48.$

This means that for task #6 the difference between minimum angles of elbow flexion from the two locations is 2,5 times (highlighted) greater than the difference between corresponding F_ROMs, and that the difference between maximum angles of elbow flexion is 1,5 times (highlighted) greater than the same difference of F_ROMs

TABLE IV

LOCATION IMPACT. VALUES ARE MEAN AND CALCULATED BETWEEN LOCATIONS #1 AND #6 USING EQUATIONS (1) and (2) FROM METHODOLOGY. MIN AND MAX ARE FOR MINIMUM AND MAXIMUM ANGULAR VALUES.

	location impact ($LI^{1,6}$)					
joint	ELBOW FLEX		THUMB ADD		IND FINGER PIP	
Task # N^0	MIN	MAX	MIN	MAX	MIN	MAX
1	0,87	0,12	2,72	3,72	1,14	0,14
2	0,87	0,12	1,53	0,53	0,08	0,91
3	0,60	0,39	0,26	1,26	0,95	0,04
4	0,86	0,13	0,90	0,09	0,37	1,37
5	0,43	0,56	0,17	0,82	1,70	0,70
6	2,49	1,48	0,45	1,45	0,46	0,53
7	0,92	0,07	0,11	0,88	2,54	1,54

Task impact was calculated among all tasks and for all locations. For example, for minimum (MIN) elbow flexion from location #1 *TI* is minimal between tasks #3 and #5:

$TI_{MIN}=(22,41-25,48)/(80,56-75,77)=0,64$

and maximal between tasks #6 and #7 :

$TI_{MIN}=(19,18-28,52)/(33,57-28,19)=1,73.$

This means that TI_{MIN} varies between 0,64 and 1,73, i.e., for using mug and comb from loc #1 the difference between minimum angles of elbow flexion is 0,6 times less than the difference between corresponding F_ROMs, and that for using VCR-cassette and CD-diskette this difference is 1,73 times greater than corresponding difference of F_ROMs.

IV. DISSCUSSION

First step toward designing rehabilitation programs that addresses the patients' ability to relearn co-ordination and functioning is to have clear understanding of what resources and strategies are present in normal functioning. Comprehensive analysis of hand/ arm joint motions in various tasks (different grasping strategies) across workspace is required for better understanding of upper-limb functional needs. In our experiments, we examined F_ROM and A_ROM for nine joint motions in five joints in 7 tasks (3

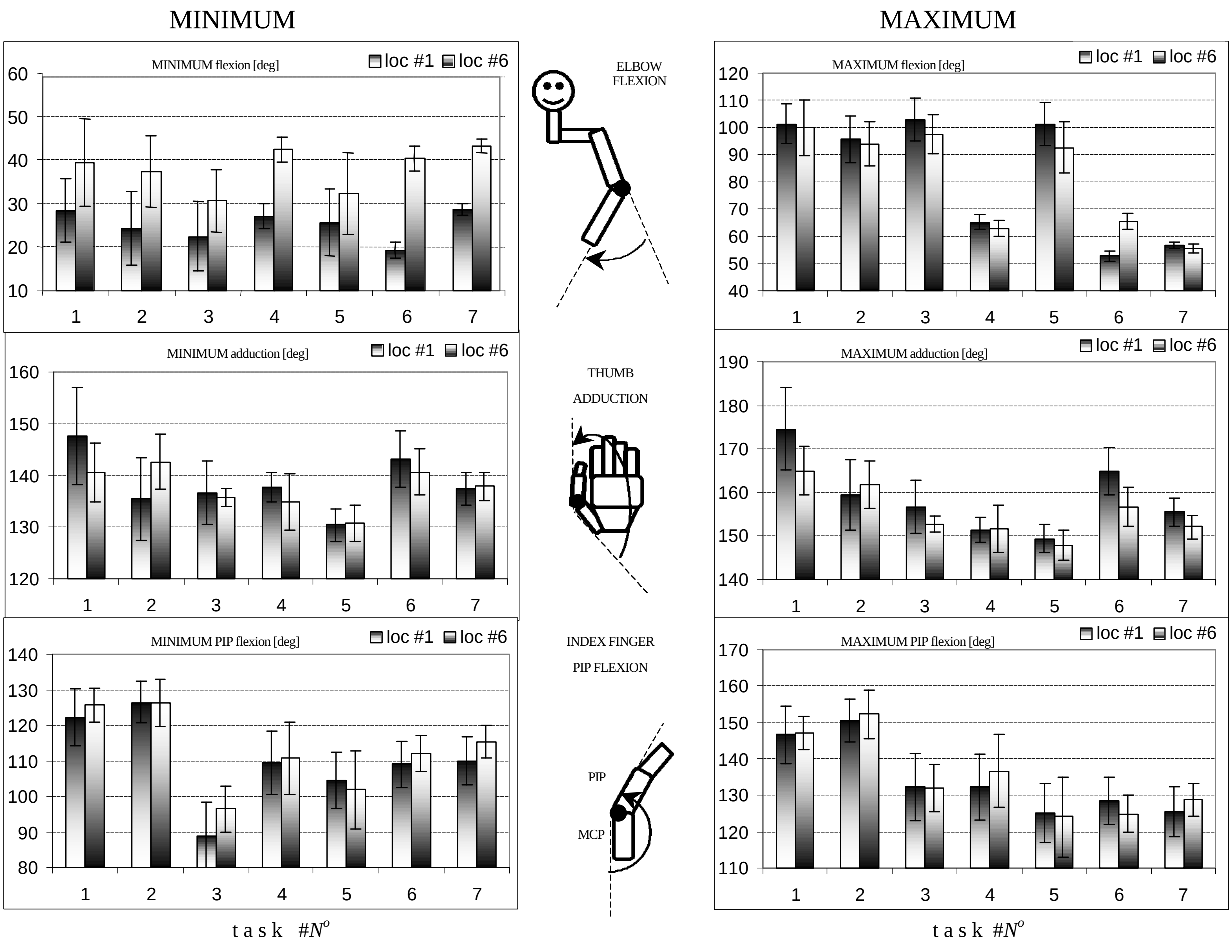

Fig.3 MINIMUM (left column) and MAXIMUM (right column) mean ±std (n=6 subjects) angles for: elbow flexion (top panels); thumb adduction (middle panels) and index finger PIP flexion (bottom panels) for object locations #1 and # 6 (see legend) in 7 tasks, Table II. Middle column shows sketches of measured angles.

grasping strategies) across 6 mostly used locations in 6 subjects. Here we present results from 3 joint rotations and 2 objects' locations. Advanced statistical procedures have to be employed to comprehend all the experimental variables (tasks, joints, locations and subjects).

Task and location of object to be used in task, both have impact on functional range of motion. Percentage of functional from anatomic range of motion differs for various object locations. The most important implication of this finding is the fact that the *LI* and *TI* can be used as guides for designing the exercise protocol in neurorehabilitation (e.g. Functional Electrical Therapy, [6]) where two variables can be altered: task and object location (controlled therapy by programmed exercise). The *LI* and *TI* provide necessary information for selecting tasks that can be accomplished, tasks that have to be externally assisted, and over all the schedule which will start with feasible, and continue with more challenging tasks.

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References

[1] S.G. Doody, L. Freedman, and J.C. Waterland, “Shoulder movements during abduction in the scapular plane,” *Arch Phys Med Rehab*, vol. 51, pp.595, 1970.

[2] L. Freedman, and R.R. Munro, “Abduction of the arm in the scapular plane: Scapular and glenohumeral movements. A roentgenographic study,” *J Bone Joint Surg*, vol. 48A, pp.1503, 1966.

[3] B.F. Morrey, L.J. Askew, K.N. An, and E.Y. Chao, “ A biomechanical study of normal elbow motion,” *J Bone Joint Surg* , vol. 62A, pp. 872, 1981.

[4] M. Nordin, and V.H. Frankel (1980*) Basic biomechanics of the musculosceletal system*. Lea & Febiger, Philadelphia, London, 2nd ed, 1980.

[5] C. Norkin, and P. Leangie, “*Joint structure and function-a comprehensive analysis*,” FA Davis Comp, Philadelphia, 1983.

[6] D.B.Popovic, T. Sinkjær, M.B. Popovic, A. Stefanovic, A. Pjanovic, L. Schwirtlich, “Functional electrical therapy (FET) for improving the reaching and grasping in hemiplegics,"*Proc VI IFESS Conf*, Cleveland, 2001.